Department of Energy

Germantown, MD 20874-1290

Safety Evaluation Report

FERMCO Scrap Ingots (13 in. OD, 2 Lengths and 11 in. OD, 2 Lengths) in the Rev. L SARP of the Steel Banded Wooden Shipping Containers (SBWSC)

Docket No. 00-19-5467

Background

The criticality confirmatory evaluation in this Safety Evaluation Report (SER) addresses four types of FERMCO Scrap Ingots described in the Rev. L SARP for the Steel Banded Wooden Shipping Containers (SBWSC). These FERMCO Scrap Ingots are unirradiated, low enrichment (1.256 wt.% U-235 max.) cylindrical uranium ingots with outer diameters (OD) of 13 and 11 inches and variable lengths (L) in the range of 1 to < 2 in. L and 2 to < 3 in. L for the 13 in. OD scrap ingots, and 6 to < 12 in. L and 12 to < 30 in L for the 11 in. OD scrap ingots. The SARP proposes to ship these FERMCO Scrap Ingots in the SBWSC Model G-4214, G-4292, or G-4273-6 in an exclusive use shipment.

The staff reviewed the criticality analyses presented in the SARP and performed independent confirmatory evaluation of criticality safety for the above FERMCO Scrap Ingots. The staff confirmed that the Transport Index (TI), and the number of packages proposed in the Rev. L SARP for each of the above FERMCO Scrap Ingots in an exclusive use shipment, meet the criticality safety requirements of 10 CFR Part 71 under normal conditions of transport (NCT) and hypothetical accident conditions (HAC). However, the staff finds it necessary to impose a restriction that the minimum ingot length and the maximum mass of U in each SBWSC package be verified during loading of the FERMCO Scrap Ingots. In addition, the shipment of the 13 in. OD FERMCO scrap ingots with lengths between 1 and 2 inches is not allowed in the SBWSC Model G-4292. Design verification testing under NCT showed a 3/4 in. gap at the edge of the SBWSC Model G-4292 as documented in the Rev. L SARP. The gap is judged to be too close to the minimum length (1 in.) of the scrap ingots, taking into consideration that the gap size may change due to variations in material properties and package dimensional tolerances, etc.

Other safety aspects (i.e., general information, structural, thermal, shielding, containment, operating procedures, acceptance tests and maintenance, and quality assurance) of the SBWSC have been reviewed for similar types of payloads in the Rev. G through Rev. L of the SARP and documented in the SER for the Rev. 11 through Rev. 17 of the Certificate of Compliance (CoC). The conclusions obtained in the earlier evaluation and SERs for the other safety aspects of the SBWSC remain valid and applicable to the payloads evaluated in this SER and will not be repeated.

Criticality Safety Evaluation

No special feature is incorporated in the design of the SBWSC for criticality control. According to 10 CFR Part 71, criticality safety must be demonstrated for a fissile material package under

NCT and HAC. The hypothetical accidents consist of a sequence of events (e.g., vertical drops, fire, and immersion in water) that would damage the package and thus often represent a more limiting condition for criticality safety analysis, i.e., 2xN damaged array analysis where N is the number of packages in the array according to 10 CFR 71.59. In the criticality analysis for the SBWSC, the applicant conservatively assumed that all SBWSC in a shipment are burned during the 30-minute hypothetical accident fire (even though the wooden boxes are most likely only charred), and that the scrap ingots are "scattered and arranged" in the most reactive configuration with optimal interspersed hydrogenous moderation and total water (30 cm) reflection, as required by 10 CFR 71.55 and 10 CFR 71.59. The staff confirmed that the applicant has used the minimum length of the scrap ingot to establish the "maximum subcritical mass" for each of the FERMCO Scrap payload types. The staff also confirmed that the applicant has indeed established the most reactive configuration for the number of scrap ingots (and packages) allowed in a shipment that would remain subcritical with an adequate safety margin.

Determination of Optimal Lattice Parameters and the Most Reactive Configuration

Determination of the maximum allowable number of scrap pieces under the most reactive configuration begins with a search for the optimal lattice parameters, i.e., pitch, axial gap, and moderator density, that would maximize the neutron multiplication factor (k_∞) for an infinite array of scrap pieces in a close-packed, hexagonal lattice. The staff found that for a given uranium ingot composition and geometry, the k_∞ is mainly influenced by the amount of water in the unit cell for the hexagonal lattice configuration. Consequently, a loosely packed array with a relatively large pitch and axial gap and low moderator density can have a mass ratio of fissile to moderator material similar to that of a tightly packed array with a smaller pitch and axial gap, but higher moderator density. Infinite arrays of ingot sections having these two types of lattice parameters will have comparable k_∞ values, and thus can be regarded as equally reactive configurations. Determination of the most reactive configuration, therefore, must consider the effect of neutron leakage, which exists only for finite array of ingots.

Since neutron leakage from a system reduces reactivity, the most reactive configuration for a finite array of ingots must be one with a minimum surface-to-volume ratio that gives the smallest total surface area for neutron leakage. A tightly packed array within a spherical enclosure and with total water reflection, therefore, should minimize neutron leakage. The staff has developed the necessary framework for determining the radius of the spherical enclosure for the finite array using iterative MCNP calculations (See "Criticality Control in Shipments of Fissile Material," J. R. Liaw and Y. Y. Liu, Proc. ANS Topical Meeting on Spent Fuel and Fissile Material Management, San Diego, CA., June 5-8, 2000, pp. 347-352). The most reactive configuration of the finite array (and the maximum number of ingots allowed in a shipment) is determined when the adjusted effective neutron multiplication factor (k_{adj}) for the 2xN damaged array satisfies the following criterion,

$$k_{adj} = k_{eff} + 0.00258 + 2 \times (0.006^2 + \sigma^2)^{0.5} \leq 0.95,$$

where k_{eff} and σ are the effective neutron multiplication factor and uncertainty, respectively, obtained in the MCNP calculations. The other constants in the equation are the code bias (0.00258) and uncertainty (0.006) obtained from benchmark calculations against the critical experiments. This is the same formula used by the applicant in the SARP, and the formula is consistent with that recommended in NUREG/CR-5661, "Recommendations for Preparing the Criticality Safety Evaluation of Transportation Packages," April 1997.

Determination of Transport Index and Maximum Number of Packages per Shipment

The applicant followed the above procedure and determined the radius of spherical enclosure for finite arrays of each type of FERMCO Scrap Ingots based on $k_{adj} \leq 0.95$. The amount of fissile material within the spherical enclosure is the "maximum subcritical mass" listed in the SARP (1,071.1, 2,323, 9,926, and 9,926 kg) that corresponds to the minimum lengths of the 13 in. OD by 1 in. L, 13 in. OD by 2 in. L, 11 in. OD by 6 in. L, and 11 in. OD by 12 in. L, FERMCO Scrap payload types, respectively. (Note: The maximum subcritical mass of 9,926 kg was based on the minimum length of 6 in. for the 11 in. OD FERMCO Scrap payload type with length between 6 and < 12 in. This value has been conservatively applied to the 11 in. OD FERMCO Scrap payload type with length between 12 and < 30 in.). The applicant determined the allowable number of packages per shipment by dividing the "maximum subcritical mass" by the amount per package for each of the four FERMCO Scrap payload types, 535, 544, 568, and 1,582 kg, respectively. The resulting number is the number of packages (2xN) per shipment. By definition, the transport index (TI) for criticality control is TI = 50/N, and the sum of TI of all packages shall be less than 100 in an exclusive use shipment.

Table 1 gives the minimum TI values and other pertinent information for the four types of FERMCO Scrap Ingots in the designated SBWSC model. The last two columns in Table 1 give the k_{adj} values from the SARP and the staff's independent confirmatory analysis for the four selected FERMCO Scrap payload types. Based on the results in Table 1, the staff has thus independently confirmed that the k_{adj} values for shipping each of the four FERMCO Scrap payload types in the designated SBWSC Model meet the subcriticality criterion of 0.95 with adequate safety margin.

Table 1. Transport Index (TI) for Criticality Control for the Four Types of 11 in. and 13 in. OD FERMCO Scrap Ingots in the SBWSC (Rev. L SARP)

Scrap Piece OD(in.) x L(in.)	SBWSC Model	Uranium/ SBWSC (kg)	SBWSC/ Shipment	Minimum TI	k_{eff}	
					SARP	Staff
13 x ≥ 1	G-4214	535	2	50.0	0.9456	0.94472
13 x ≥ 2	G-4214 or G-4292	544	4	23.5	0.9421	0.94683
11 x ≥ 6	G-4292	568	17	5.8	0.9455	0.94787
11 x ≥ 12	G-4273-6	1,582	6	16.0	0.9455	0.94787

It should be noted that the TI values in Table 1 are based on the minimum length of the scrap ingot for each of the four FERMCO Scrap payload types. According to the "maximum subcritical mass" rule established in the SARP and confirmed in the staff evaluation, it is conservative to apply the rule in a shipment of longer ingots based on the TI value established for criticality control of ingots of the same outer diameter but shorter length. For example, it is conservative and critically safe to use the minimum TI value (50.0) and the maximum allowable number of packages (2) per shipment established for the 13 in. OD x 1 in. L ingots to ship the 13 in. OD FERMCO Scrap Ingots with length L > 1 inches.

It should also be noted that the value of the amount per package listed in Table 1 needs to be strictly followed for each of the FERMCO Scrap payload types. Due to the possibility of having variable length (and weight) scrap ingot in each payload type, the loading may not be based on counting the number of ingots in the designated SBWSC Model. The values of the amount per package listed in Table 1 set the limit for each FERMCO Scrap payload type.

Summary

The staff has evaluated the criticality safety analyses presented in the SARP for the four payload types of the FERMCO Scrap Ingots with outer diameters of 11 in. and 13 in. and four lengths. The staff has performed independent calculations and confirmed that the minimum TI values (and the corresponding maximum number of packages) for the four types of the FERMCO Scrap Ingots listed in Table 6.1-2a(D) of the Rev. L SARP* are conservative and meet the 10 CFR Part 71 requirements under NCT and HAC. However, the staff finds it necessary to impose a restriction that the minimum ingot length and the maximum amount of U per Package in each SBWSC model be verified during loading of the FERMCO Scrap Ingots. In addition, the shipment of the 13 in. OD FERMCO scrap ingots with lengths between 1 and 2 inches is not allowed in the SBWSC Model G-4292.

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Date: DEC 6 2000

*There is an error in Table 1.2.3-2 in the Rev. L SARP. The criticality transport index/package limit for the last entry (11 in. OD x 12 to <30 in. L) should have been changed from 13.1/7 to 16.0/6 to be consistent with those in Table 6.1-2a(D) of the Rev. L SARP.